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GUIDANCE AND CONTROL OF ANTI-TACTICAL BALLISTIC MISSILES.(U)

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This technical report covers the efforts undertaken to review guidance and control development status of a interceptor vehicles of tactical ballistic missiles. Technology needs are indentified for promising concepts being pursued by other agencies. Of particular interest in this review is the Navy High Angle threat (HAT) defense concepts.

GUIDANCE AND CONTROL OF
ANTI-TACTICAL BALLISTIC MISSILES

by
H. Eugene Worley
PRINCIPAL INVESTIGATOR

6 November 1980

FINAL TECHNICAL REPORT

This research was performed for the US Army Missile Command
Redstone Arsenal, Alabama 35898

under

Contract No. DAAH01-80-M-0399

CONTROL DYNAMICS COMPANY
221 East Side Square, Suite 1B
Huntsville, Alabama 35801

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ABSTRACT

This technical report covers the efforts of the Control Dynamics Company in completing the requirements set forth in the scope of Work dated 13 August 1980 entitled "Guidance and Control of Anti-Tactical Missiles". Under this effort the guidance and control development efforts for interceptor vehicles of tactical ballistic missiles were investigated. The results of this effort are summarized and recommendation for future efforts are made.

SECTION I. INTRODUCTION

As the US Army Missile Command embarks on the ambitious task of defining the systems required to develop an anti-tactical ballistic missile defense system, it is prudent to investigate other avenues of approach to similar threats. These approaches are found not only in the strategic Ballistic Missile Defense (BMD) concepts but in the Navy High Angle Threat (HAT) defense concepts. Although there is a wide disparity in the total threat scenario for BMD and HAT, there are a number of areas of technical investigations that are of mutual concern to BMD, HAT and the Anti-Tactical Ballistic Missile (ATBM). Details of these areas of commonality and similarity are contained as Appendix A, Appendix B and Appendix C to this report.

SECTION II. DISCUSSION

The major effort expended was in the review of the various HAT contractor reports and participation with the Navy in the formulation of their future activities plan. The reports reviewed are as follows:

1. "High Angle Threat (HAT) Defense Systems Concepts Study (U)", SECRET Document by General Dynamics Company dated April 1979.
2. "High Angle Threat Defensive Systems Concepts (U)", SECRET Document by Hughes Aircraft Company dated 22 June 1979.
3. "HAT Weapon System Concept Formulation Study (U)", SECRET Document by General Research Corporation dated 22 June 1979.
4. "High Angle Threat Weapon System Formulation Study (U)", SECRET Document by McDonnell Douglas Corporation dated 1 May 1980.

An overview of these reports is presented in Appendix A entitled "Review of High Angle Threat (HAT) Defense Concepts". These results were presented to the HAT Review Group on 15-16 October 1980, and these presentation materials are contained as Appendix B entitled "High Angle Threat (HAT) Defense Concepts Commonaility with Anti-Tactical Ballistic Missile (ATBM) Concepts". Because of its sensitive nature, a portion of the document which comprises Appendix A has been deleted from this report. However, the full document is in the hands of the contract director, Dr. Pastrick.

CONTROL DYNAMICS COMPANY

221 East Side Square, Suite 1B
Huntsville, Alabama 35801

Telephone
(205) 539-1342

August 22, 1980

FROM: Eugene Worley, Control Dynamics Company

TO: Dr. H.L. Pastrick, DRSMI-RGN

SUBJECT: Review of High Angle Threat (HAT) Defense System Concepts

At your request, we have reviewed the reports provided on the HAT (High Angle Threat) Defense Concepts. These reports covered the work by four contractors; General Dynamics, McDonnell Douglas, General Research Corporation, and Hughes. In addition, we are prepared to support your organization in an evaluation and planning meeting at the Naval Surface Weapons Center on 27-28 August 1980.

General Comments relating to all of the contractors are as follows:

1. The basic study was oriented toward the defense of a Navy target or targets against a coordinated attack from a number of sources (land and sea) with particular emphasis to those threats that attack from a high angle relative to the horizontal.

2. The key issues arrising are then: (a) Detection of the potential threat with sufficient time and accuracy to initiate appropriate action; (b) Tracking of potential threats with sufficient accuracy to enable accurate predictions of the trajectory during exoatmospheric and endoatmospheric flight; (c) Formulation of real time battle strategy that would deploy the defenses against this threat in an optimum manner; (d) Guidance and control of defense missiles to within the range of appropriate onboard sensors; (e) Autonomous guidance and control of the defense missiles against the designated threats; and (f) Fuzing and subsequent detonation of the kill weapon.

3. Because of the emphasis on system analysis and top level trades, there was very little detail available on subsystem analyses, detail subsystem trades or technical results that would support performance requirements. The most detail appeared to be available in the sensor area due to the stringent requirements that exist as a result of the range, accuracy, and discrimination requirements.

4. Concerns/issues arising are as follows:

   a. Early detection of potential threats is crucial;

   b. Peculiar interceptor designs are required for endo or exo atmospheric intercept;

   c. The employment of 2 on 1 targeting reduces leakage possibilities but is made difficult if nuclear warheads are employed;

d. Shoot-look-shoot philosophy further reduces leakage but requires an assesment of kill and places stringent requirements on both targeting philosophy and guidance implementation;

e. Terminal phase guidance and control success will play a strong role in overall mission success but was not adequately covered due to the system nature of the study (Some contractors assumed that whatever control acceleration was required was instantly available while others indicated that control may be an area requiring the development of new technology);

f. The end game philosophy will not only require guidance and control to a position but also with proper roll and azimuth coordinates;

g. Multiple targeting will require efficient and practical energy management schemes;

h. Intertial guidance errors will probably be the largest component in the uncertainty volume at hand-over to the autonomous interceptor guidance system;

i. Communications and data management are sure to be hardware/software drivers;

j. Results of nuclear/non-nuclear trades will have a significant impact on guidance, navigation, and control (GNC) requirements;

k. GNC capabilities should/must be factored into the selection process for not only the "best" system, but also into the actual battle selection of the "optimum" interceptor to deploy:

H. Eugene Worley

HIGH ANGLE THREAT (HAT) DEFENSE CONCEPTS

COMMONALITY WITH

ANTI TACTICAL BALLISTIC MISSILE (ATBM) CONCEPTS

INTRODUCTION

ISSUES HELD IN COMMON
- IR SENSORS
- GUIDANCE, NAVIGATION, CONTROL

SUMMARY

INTRODUCTION

In 1978 the US Army Missile Command (MICOM) embarked on a task to develop an advanced guidance and control system for future missiles. The purpose of this effort was to "Leapfrog" systems currently under development in order to meet the stringent demands and constraints imposed by targets with predicted characteristics of the 1990's and beyond and by the predicted battle environment of that time. Recently this activity has been expanded to include other system design impacts (e.g. sensor technology required) and to investigate the peculiar requirements imposed by a Tactical Ballistic Missile (TBM). Thus our review and evaluation of High Angle Threat (HAT) Defense System Concepts was conducted against this background, and our comments are directed toward identifying areas of mutual interest and commonality.

ISSUES UNIQUE TO NAVY HAT DEFENSE

1. SPY-1A shipboard radar as part of the Aegis Weapon System

2. Requirement for interceptor to be compatible with the standard shipboard MK-10 launcher

3. Concern for interceptor ignition blast overpressure

ISSUES UNIQUE TO NAVY HAT DEFENSE CONCEPTS

There are several issues that, because of particular requirements or circumstances, are not now, nor are they likely to be, items of mutual interest to both the NAVY HAT and the MICOM ATBM activities. It is important to understand what these areas are and to understand why they exist in the event there is any change in requirements of assumptions in the future. Some of these relate to decisions made in the past regarding configurations and onboard ship requirements; such as the Aegis Weapon System and the desirement for the Navy interceptor to be compatible with the standard shipboard MK - 10 launcher. These issues coupled with the low allowable ignition overpressure will tend to drive the Navy interceptor design but are of no concern to the design of the ATBM.

ISSUES COMMON TO HAT DEFENSE AND ATBM DESIGN

1. Requirement for early warning

2. Endo-atmospheric intercept

3. Battle management

4. Non-nuclear kill

I. Infrared Sensor Technology

II. Guidance, Navigation, and Control Technology

ISSUES COMMON TO HAT DEFENSE CONCEPTS AND ATBM DESIGN

There are a number of critical design issues and trades that are of mutual concern and where cooperation and exchange of ideas, technology and design decisions can be of significant benefit to both the MICOM and the Navy. The nature of the threat dictates that some form of effective, reliable, and efficient early warning system be developed. The consideration of endo-atmospheric kill of the threat is one that both agencies share. In addition, for similar reasons to the Navy, MICOM rates the requirement for a non-nuclear kill as a high priority. The number of threats and interceptors in the air at the same time is a major concern as it impacts the design and programming of the computer that will manage the engagement. (However, we are not prepared to comment on the efficacy of battle management schemes since the Division of MICOM that we represent does not have that responsibility).

We can now define the set of issues that is left due to elimination of unique HAT issues coupled with the current ongoing ATBM activity at MICOM. These issues can then be expressed as: I. Infrared Sensor Technology, and II. Guidance, Navigation, and Control Technology.

INFRARED SENSOR PERSPECTIVE

1. Target acquisition & Early warning
   * Launch phase target data available and performance adequate
   * IR data sparce after motor burnout and performance determination questionable

2. Missile Guidance sensors issues
   * Concern with handoff from acquisition system to narrow field of view IR seeker
   * Seeker environment during operation
   * Development of seeker that can accommodate large field of view, spatial resolution and high data rate
   * Large scale linear array processors
   * Window material

INFRARED SENSOR TECHNOLOGY

The assessment of IR Sensor technology and requirements is presented from two perspectives: (1) IR Target initial acquisition and tracking and (2) IR guidance sensors for the terminal phase.

(1) The design of a sensor system for remote infrared surveillance, acquisition, and tracking of TBM threats requires a detailed knowledge not only of the target, but also of the background and the propagation characteristics of the atmosphere between the threat and the sensor. The long range detection required coupled with the requirement for all weather operation and very low levels of target intensity demand a high altitude surveillance platform (an altitude of 40,000 feet or higher has been selected by MICOM). It has been determined in this study that with the current data base the predicted sensor performance characteristics are sufficient for the launch detection and tracking. However, it is felt that a major data gap exists with the infrared characteristics of the threat over a significant portion of the flight after motor burnout. Consequently, the performance of sensors after motor burnout can not be specified with certainty. Further effort is underway to close this data gap and thereby make an appropriate assessment of sensor capability.

(2) The selection of the seeker spectral band of operation, field of view, resolution, and sensitivity involves an optimization problem in design where physical limitations, technology limitations and/or costs considerations will necessitate some sort of compromise. For example, large fields of view and resolution tend to be mutually exclusive. The minimum field of view would be selected to be compatible with the target handoff accuracy of the target acquisition system. Resolution of the seeker can then be established with the constraints of technology, diffraction limitations, complexity, and cost. The sensitivity of the chosen design would essentially then be set with the exception of further enhancements through selection of the detection material. In addition high frame rates are required to accomplish the terminal phase of the intercept with the very high closing rates involved. The performance of the seeker may also be adversely affected by the vibration, thermal and shock environment to which it is exposed before and furing operation.

GUIDANCE, NAVIGATION AND CONTROL

a. Determination of controllability and observalibility required by kill mechanism

b. Guidance Law

1. Conventional or new development?
2. Accuracy potential
3. Calculation of "time to go"
4. Succeptability to threat maneuvers
5. Flexibility
6. Computer implementation

c. Control Law (Vehicle autopilot)

1. Authority
2. Stability (rigid body + flexible structure)
3. Performance
4. Flexibility
5. Redundancy (logic and actuators)
6. Computer implementation
7. Sensitivity
8. Number of degrees of control required
9. Consideration of additional control authority (e.g. "bank-to-turn")

GUIDANCE, NAVIGATION, AND CONTROL

The ATBM activity at MICOM in this area is currently investigating several potentially fruitful avenues for developing technology to be able to satisfactorily meet the requirements of the 1990s. An orderly program is underway that progresses from a definition and evaluation of candidate G&C systems to a demonstration of "Proof-of-Concept" of the selected system or systems. It has already been demonstrated in this activity, for example, that analytically Proportional Navigation Guidance (PNG) and existing optimal guidance formulations do not provide sufficient accuracy to meet the stringent ATBM requirements. A focused activity is underway to enhance the state of the art by exploiting the expected strengths of both advanced digital technology and new optimal G&C formulations.

The technical program approach is to capitalize on the research efforts being performed in and under contract to the G&C Analysis Group at MICOM. Typical areas of intense activity include: optimal guidance research, research on maneuver estimating filters, Disturbance Accommodating Control (DAC) theory, investigation of the very difficult but crucial time-to-go problem, and the application of advanced digital technology to implement the most promising of the designs into an onboard digital G&C system, including the development of a digital autopilot and appropriate digital filters.

CONTROL DYNAMICS COMPANY

221 East Side Square, Suite 1B
Huntsville, Alabama 35801

October 18, 1980

MEMO:

TO Dr. Harold L. Pastrick, DRSMI-RGN
FROM: Dr. H. Eugene Worley
SUBJECT: HAT Review meeting, 15, 16 Oct 1980

The agenda for the subject meeting is contained in the Enclosure. This agenda was essentially followed with the exception that the attempt to synthesize one or two viable concepts was not successful. The failure to meet this objective was probably attributal to the difficulty of the task as well as a lack of clear objectives and groundrules. Not only is the defined Navy threat composed of elements that are doubtful future threats, but the degree of Navy resources available to the HAT defense is apparently open to some discussion and to some arbitrary definition (e.g. How much of the Aegis Spy-1 radar system resource can/will be available for HAT defense?). It is felt that our participation, however, has been of value both to the Navy and to MICOM in that we have learned a significant amount about potential threats, technology drivers, technology voids, and system constraints and considerations. Additionally, it is apparent that a study directed toward, "Tell all you know about HAT(read TBM) defense", without a good definition of not only the projected threat, but also the fundamental groundrules, assumptions, resources, and system performance requirements will lead to a rather general work package as a result and more detailed activities will be required to unravel the ambiguities that result. It is our judgement that MICOM technical personnel must maintain a strong hand in not only the evaluation of results, but in the formative stages of the program plan as well (this appears to be the current thrust of MICOM activities). The report is organized into mission phases as follows:

A. DETECTION AND BOOST TRACK

B. POST BOOST TRACK

C. BATTLE SPACE SELECTION

D. INTECEPTOR DESIGN

E. WARHEAD/FUSE

A. DETECTION AND BOOST TRACK

All systems require an early detection of the threat, with the most stringent requirement arising out on an exo-atmosphere engagement of the threat. Potential systems to perform this function are as follows:

1. DSP Satellite
2. Infrared sensor aircraft platform
3. Radar aircraft platform
4. Shipboard radar (Aegis Spy-1)

The temperature of the exhaust plume and the resolution capability of IR sensors makes the use of IR platforms an attractive system. However, the requirement to have from 1 to 4 aircraft on station at all times puts a severe stress on Navy resources and may be totally prohibitive. The in-house Navy scenario utilized land based Remote Pilotless Vehicles (RPV) in order to provide this function at essentially no expenditure of fleet resources. However, during the course of the meeting, it was discovered that the Spy-1 radar system had the capability to perform this function if the timeline requirements imposed would permit it. It was stated, without supporting data, that for the endo-atmospheric intercept the Spy-1 radar had the capability to do the job. The remaining question, assuming that this is true, was: could the Spy-1 be diverted from its other duties to perform the HAT surveillance function? The general feeling was, probably yes. However, it is interesting to note that none of the four contractors perceived that this was a viable alternative.

B. POST BOOST TRACK

The requirements here become an even stronger function of the planned intercept region, of course. If a exo-atmosphere intercept is planned, then very accurate data must be obtained as quickly as possible and relayed to the command station. The competing systems for exo-atmosphere intercept appear to be as follows:

1. IR aircraft platform
2. IR/Laser aircraft platform
3. IR rocket probe

The rocket probe was considered by Hughes in order to get the IR sensors as far out of the atmosphere as possible to minimize the effects of atmospheric absorption of the long wave length IR emission from the threat skin. The probe would be launched upon a signal from the early warning system. However, the conflicting requirements of long stay time and sky background (not earth), in addition to the use of nonreuseable resources, places the efficacy of this approach in some doubt.

Apparently, BMD has done considerable research into the utilization of IR sensors to perform this function, and consequently there was a strong presentation by Teledyne/Brown Engineering in support of IR sensors. Depending on the quality of the data required, one or more IR platforms are required. A digression is probably in order here to discuss the type and nature of data available from IR sensors. One reading from one IR sensor platform provides angle only data on the objects in the field of view of the sensor. In order to commit an interceptor, a complete state vector is required. It is possible, and simulation data were presented to support the theory, to construct the state vector for the sensed object through a process known and presented as correlation. The process involves taking samples of the angle to the threat at various times (3 samples spaced 10 seconds apart are sufficient according to Brown). Assuming that the threat is acted on only by gravity (no maneuvers or thrusting) and that the acceleration environment of the platform is known (essentially one g), then a Kalman filter formulation is utilized to develop a state vector with an associated error volume. This determined error volume then can be propagated forward in time to produce the predicted trajectory of the threat. The error volume is in the shape of a cigar, being thin normal to the line of sight between the sensor and the threat (on the order of 0.1 nM) and being long along the line of sight (1 to 10 nM.) An independent sensor located on another platform would produce an error volume of similiar characteristics. The intersection of these two error volumes would then have the effect of significantly reducing the error, and a very accurate estimation of the state vector of the threat can be produced. It was presented that such a system handling a large quantity of objects in the field of view has been successfully demonstrated. However, since IR platforms must be at least 40,000 feet high in order to minimize the absorption of the atmosphere and also are required to be on station for extended periods of time (one would use the same platform for the surveillance and track function) a significant stress is placed on the Navy to support this function. The use of a laser sensor for the track function could potentially reduce the number of platforms required to only one since accurate range and range rate data are available from one sensor. However, the indicated range capability of the laser tracker does not appear to support an exo-atmosphere intercept. If the intercept is to be endo-atmosphere, then the door is opened again to potentially utilize the onboard radar sensors and thus solve the resources problem associated with maintaining a number of surveillance and track aircraft in the air all the time.

C. BATTLE SPACE

Although the last thing that happens in the HAT defense scenario is the engagement, decisions made in this regard ripple through the entire system design. The battle regions can be stated as follows:

1. Exo-atmosphere
2. Endo-atmosphere

The selection of the region in which to engage the threat is driven by consideration of leakage requirements (an extremely low leakage requirement will dictate a re-engagement after an unsuccessful first attempt, thus driving at least the first engagement to be as high as possible), maneuver capability of threat (get him before he maneuvers), signature of threat (booster attached exo-atmosphere confuses IR track and kill), detection capability, and interceptor capability. Unfortunately, no system was presented that would work with high confidence in either exo or endo atmosphere. The hit-to-kill concept exo-atmosphere suffers from the fact that there is no assurance that an IR guided vehicle hitting the centroid of the IR signature (probably the engine) will kill the warhead, and the endo-atmospheric requires the development of a very sophisticated and precise guidance scheme and associated high performance interceptor.

D. INTECEPTOR DESIGN

The major contribution in this area by the reviewers at the subject meeting was in the area of propulsion system design. It was stated that the propulsion requirements appeared to be basically within the state of the art, and their recommendation of a propulsion system must wait the selection of the type of vehicle required. Surprisingly, there was very little (in fact none other than that covered in our presentation) information regarding the guidance, navigation and control problems. John Hopkins Applied Physics Labs (APL) had the designated responsibility for this area but they did not make any comments regarding the interceptor G&C. It is therefore felt that there may be some avenues here where the MICOM expertise can be utilized by the Navy. There certainly appears to be a void within the Navy organizations in this regard.

E. WARHEAD/FUSE

This area did not receive much attention since the expert in this area did not come to the meeting. However, it was stated that nuclear warheads were not desirable (apparently due to the effects on other systems operation), Selectable Aimed Warheads (SAW) did not have satisfactory performance (a fact questioned by some in attendance), and Self Forging Fragement (SFF) warheads appeared to have satisfactory performance. It was clear from the discussion on fusing that there is a strong coupling between the fusing operation and the guidance computations. However, there is a desire on the part of the fuse designers to be completely independent from the rest of the system, that is they wish to be able to operate even if the rest of the system doesn't. The stated key issues in the design of a successful fuse are performance, autonomy, countermeasures capability, survivability, target versatility, ability to handle a direct hit, and the usual risk development time and cost. It was stated that an operational Navy fuse (MK 45) could probably be modified to do the job, with significant development risks in handling the large closing velocities involved.

CONTROL DYNAMICS COMPANY

SUMMARY

As stated in the introduction, the task of obtaining a viable and effective system to serve as a defense to High Angle Threats is very difficult. However, assuming that the threat as defined is real and that the Navy must field the most efficient defense against it, then one is driven to rely on proven resources. The most fundamental question that drives the entire defense scenario is: Can non-nuclear devices kill the threat with high probability? Based on today's technology this question can not be answered in the affirmative with confidence. A number of technology thrusts are underway, of course, and these may prove very successful but the earliest, reliable defense system seems to include a nuclear kill of the threat. The decision for nuclear kill dictates an endo-atmospheric intercept of the threat, which affords the detection and track system more time and enhances the probability of the Spy-1 radar system being adequate. Consequently, I have hypothesized a deployment strategy that evolves from a system with a nuclear kill to the high technology concept of an exo-atmospheric kill with an early warning track IR platform.

In summary the system that is felt would have the greatest probability of doing the job in the minimum time with the least strain on Navy resources is as follows (assuming the Spy-1 is all that it is cracked up to be and is made available to HAT):

Early System

Early warning and boost track	Spy-1 radar
Post boost track	Spy-1 radar
Engagement	Endo-atmosphere
Booster guidance	"Optimal" with radar sensor
Warhead	Low yield nuclear

First Product Improvement

Early warning and boost track	IR platform
Post boost track	IR platform
Engagement	Endo-atmosphere
Booster guidance	"Optimal" with radar sensor
Warhead	Non nuclear

Next Product Improvement

Early warning and boost track	IR platform
Post boost track	IR platform
Engagement	Exo-atmosphere
Booster guidance	Inertial plus IR guided terminal
Warhead	Hit-to-kill

H. Eugene Worley

ENCLOSURE

AGENDA

HAT EVALUATION MEETING

0900-1600 15-16 Oct 1980

Wednesday, 15 Oct 1980

Review of 27-28 Aug meeting	J. Walchak	0900-0915
Review of action items	J. Walchak	0915-0930
Presentation of Evaluation Criteria		0930-1130
ATBM/Systems	MICOM	
Interceptor, G&C	APL	
Warhead, fuze	NWC	
Propulsion	NAUSEA/NSWC	
Battle management	APL	
Early Warning	TBE	
D^3 and track	TBE	
C^3 and handover	PME 108	
Optical adjunct	TBE	
Lunch		1130-1230
Defense Concepts Evaluation	ALL	1230-1530
MDAC		
General Dynamics A,B,C		
GRC		
Hughes A,B		
NSWC strawman		

Thursday, 16 Oct 1980

Defense Concepts Evaluation (Con't)	0900-1000
Synthesis of Concept(s)	1015-1145
Lunch	1145-1245
Synthesis of Concept(s)	1245-1500
Wrap-up	1500-1530

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